Observations of Vorticity and Turbulent Properties in a Tidal Channel

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LONG-TERM GOAL

Our goal is to contribute to a better understanding of basic processes in shallow water and coastal flows, in order to provide better, more physically based parameterizations for coastal models. We seek to understand how high Reynolds' number coastal flows interact with boundaries producing tangential stress, dissipation, mixing and secondary circulation. In the future, we intend to compare the field observations with direct numerical simulations.

SCIENTIFIC OBJECTIVES

The objective is to observe mean and turbulent flow quantities in an energetic tidal channel over a flat, smooth channel bottom and over topography. These observations throughout the water column are being contrasted with published results from current meters on tripods, from wind tunnel experiments, and theory. Particular emphasis is placed on the observation and interpretation of small-scale vorticity in conjunction with other mean and turbulent flow quantities.

APPROACH

The approach is to measure vorticity, velocity, dissipation and water properties within bottom boundary layers in local tidal channels with variable bottom topography.
The most notable sensor is an electromagnetic vorticity detector which determines a component of relative vorticity based on the principles of motional induction. An experimental site in Pickering Passage in the S. Puget Sound has been selected based on a detailed multi-beam bathymetry survey. Topographic relief is less than 0.2 m for distances of 200 m upstream of the measurement site. Other locations offer regular patterns of bedforms, such as waves with heights of 0.5 - 1 m and wavelengths of 20 - 30 m and a prominent ridge about 500-m long, rising 10 m above a flat bottom. In addition to velocity and vorticity, observations of temperature, electrical conductivity, pressure, altitude above the bottom, and turbulence kinetic energy dissipation rate are obtained.

Vehicle attitude (i.e., pitch, roll, yaw, pitchrate and rollrate) is measured to correct vorticity and velocity for vehicle motion and to rotate observations in true horizontal and vertical components. The instrument can be slowly winched vertically while the vessel is anchored or slowly moving.

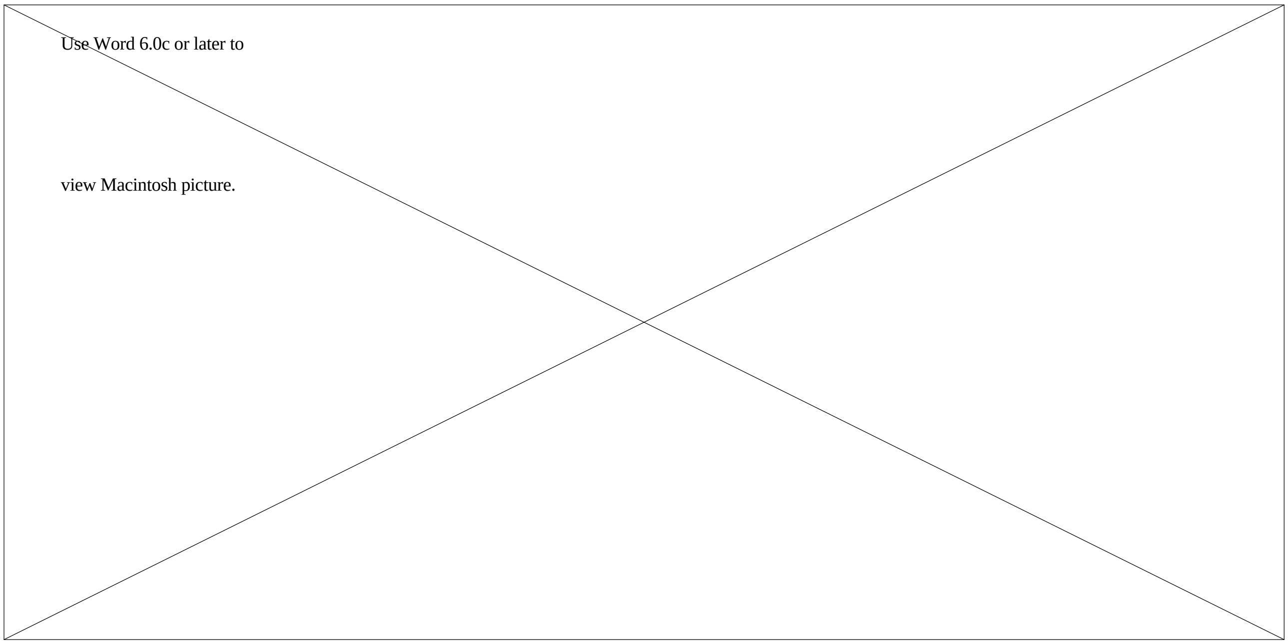

Fig. 1. Drawing of the EMVM tow body. The vehicle is made of PVC to avoid corrosion electric signals and carries about 200 kg of granite to provide stability. The instrumentation consists of the vorticity meter sensor and electronics, an acoustic Doppler velocimeter, an altimeter, temperature and conductivity sensors, a kinetic energy dissipation sensor, a turbidity sensor (or a second dissipation sensor), and attitude sensors (including a magnetic compass in the tail).

WORK COMPLETED

The SonTek ADV current meter has been installed to provide an independent measurement of small scale velocity for comparison with that observed by the Vorticity Meter (VM) sensor. Some system modifications were made to support this instrumentation and accommodate the data flow. A technical report on the design and operation of the VM was published in FY96 and widely distributed. A paper was prepared for the Timberline Workshop on Turbulence Sensors in October. A comprehensive manuscript on the Vorticity Meter has been submitted to J. Tech for consideration in a special issue resulting from the Timberline Workshop. The Kaese, Hinrichsen and Sanford paper on a method to determine water density from historical data and in situ temperature profiles, such as from XBTs, was published. We conducted a profiling experiment in Pickering Passage in

January 1997. Evaluations of the newly installed SonTek ADV sensor were conducted before the instrumentation was used in an experiment.

RESULTS

Our results consist of studies of the theoretical and empirical response of the velocity and vorticity sensors, the execution of several field experiments and the interpretation and publication of our observations. The measurements were obtained in Pickering Passage, WA, as the sensor platform was slowly raised and lowered from an anchored vessel. During periods of strong flow, the vertical structure of all properties confirms the expectations for a fully developed turbulent bottom boundary layer. EMVM observations of velocity and vorticity are shown to be in agreement with the theoretical response function applied to spectra of homogeneous isotropic turbulence. With confidence in the performance of the new sensor, we use it to investigate classic and new aspects of wall-bounded turbulence in the tidal flow. Results of data taken during vertically homogeneous conditions are summarized as follows:

- A classic log layer in streamwise velocity is observed.
- The Reynolds stress profile is linear from a maximum near the bottom to nearly zero at the water surface, a pattern in agreement with classic channel flow.
- The vertical flux of spanwise vorticity is computed and confirms the expectation that it is uniform in the vertical because the only source and sink of horizontal vorticity is the seabed. Once above the bottom, the spanwise vorticity flux is uniform.

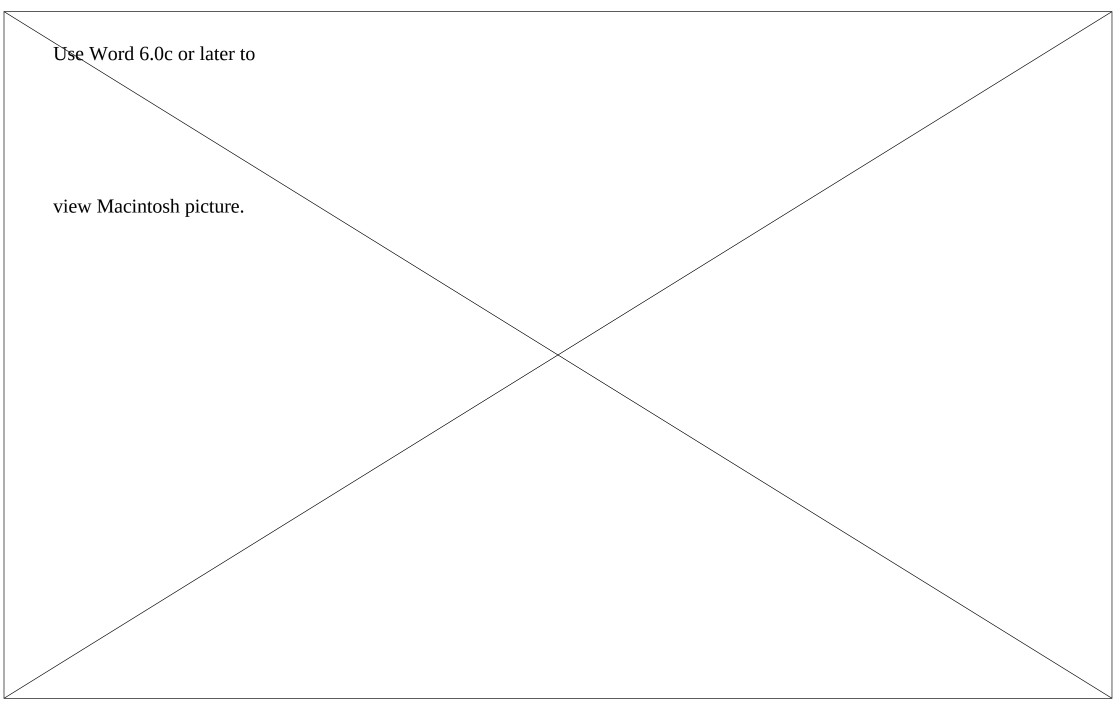

Fig. 2. Vertical profiles of (a) momentum and (b) vorticity fluxes. The red curves denote observed profiles. The shading represents the 95% confidence interval. The blue line is the linear fit of the observed profile. The horizontal dashed line marks the water surface.

- The momentum and vorticity fluxes are used with the respective vertical gradients of mean velocity or vorticity to estimate eddy diffusivities. Both computations yield similar values around .02 m^2/s.
- Enstrophy and dissipation are highly correlated, suggesting that the former (taken by a 0.1-m sensor) can be used to determine the latter. The relation $\varepsilon = 600\ \nu$ enstrophy is observed.

During a period of strong stratification, observations showed:

- The streamwise velocity has a log-linear profile
- The Reynolds stress has a rather complicated vertical profile
- The enstrophy and epsilon are highly correlated as in the homogeneous case.

Evaluation of the Mellor-Yamada parameterization was conducted using observed turbulence variables and estimated eddy viscosity. Preliminary results demonstrate that the Mellor-Yamada method predicts the eddy viscosity with useful accuracy.

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Fig. 3. Vertical profiles of observed mean eddy viscosities (solid curves) in homogeneous and stratified flows. The shading denotes the 95% confidence interval. Dashed curves are the predicted eddy viscosities based on Mellor and Yamada (1974) level 2 model.

IMPACT

The ability to obtain profiles of mean and turbulent water properties quickly at many sites will increase our understanding of the interaction of shallow water flows with bottom and sidewall topography. This understanding will increase our ability to numerically model coastal flows and processes.

TRANSITIONS

There was interest from colleagues at the Timberline Workshop on Turbulence Sensors in obtaining vorticity sensors for their research. There was discussion about smaller sensors, ones more suitable for a wide variety of applications. The instrumentation has proven to be ideal for several naval applied programs. In particular, it is a principal observing system in a potential Bottom Ocean Wake Experiment, a 6.2 project supported by Dave Johnson of ONR.

We have conducted a model of ELF propagation in the coastal wedge, the region between the shoaling bottom and the beach. Our purpose was to study use of deliberate EM emissions for the navigation of and communication with autonomous submerged instruments. In addition, we computed distortions to applied EM fields from buried conducting bodies near the beach and communicated these model results to ONR in a whitepaper.

RELATED PROJECTS

Examples of such relationships are mentioned in the Transitions (above). It is certain that the sensor is appropriate for participation with many science projects now underway in shallow water BBL, mixing, internal waves, bottom stress, and so forth.

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